Search for Very High Energy Emission from Gamma-Ray Bursts using Milagro

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Abstract. Gamma-Ray Bursts (GRBs) have been detected at GeV energies by EGRET and models predict emission at > 100 GeV. Milagro is a wide field (2 sr) high duty cycle (> 90%) ground based water Cherenkov detector that records extensive air showers in the energy range 100 GeV to 100 TeV. We have searched for very high energy emission from a sample of 106 gamma-ray bursts (GRB) detected since the beginning of 2000 by BATSE, BeppoSax, HETE-2, INTEGRAL, Swift or the IPN. No evidence for emission from any of the bursts has been found and we present upper limits from these bursts.

Keywords: gamma-ray sources; gamma-ray bursts; astronomical observations: gamma-ray
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Some of the most important contributions to understanding gamma-ray bursts (GRBs) have come from observations of afterglows over a wide spectral range [1]. Many GRB models predict very high energy (VHE, > 100 GeV) emission from GRBs at a level comparable to that at MeV energies (e.g. [2, 3]). EGRET detected several GRBs at energies above 100 MeV, indicating that the spectrum of GRBs extends at least out to 1 GeV, with no evidence for a spectral cut-off [4]. A second component was also found in one burst which extended up to at least 200 MeV and had a much slower temporal decay than the main burst [5]. At very high energies, there has been no conclusive emission detected for any single GRB, though a search for counterparts to 54 BATSE bursts with Milagrito, a prototype of Milagro, found evidence for emission from one burst, with an after trials significance slightly greater than 3σ [6]. At these high energies, gamma rays are attenuated by the redshift-dependent extra-galactic background light (EBL) [7], making the detection of VHE emission from GRBs very challenging.

A search for an excess of events above those due to the background was carried out for each of the 106 satellite-detected GRBs in our sample (see Table 1). These represent all the GRBs known to have occurred within the field of view of Milagro during its first seven years of operations (2000-2006)[2]. Milagro detected no significant emission from any of these bursts, and fluence upper limits are given in Table 1.

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[2] GRB 060218, due to its long duration of more than 2000 s moved out of Milagro's field of view after the start of the burst. The limit presented here is for the initial 10 s hard spike reported by the instrument team.

TABLE 1. GRBs in the Milagro field of view (2000-2006). Column 1 is the GRB name. A superscript refers to the number of IPN error regions in the Milagro field of view. A superscript of one implies only one of two error regions fell in the Milagro field of view, while a two implies that both did, and they are listed one after the other. Column 2 gives the duration of the burst (in seconds), column 3 the zenith angle (in degrees), column 4 the measured redshift, column 5 the satellite(s) detecting the GRB, and column 6 gives the Milagro 99% confidence upper limit on the 0.2–20 TeV fluence in erg cm^{-2}. Numbers in bold (also labelled with a [#]) take into account absorption by the EBL (using the Primack 05 model) for a redshift given in column 4. Those with three dots imply the redshifts are so high that all the emission is expected to be absorbed.

GRB	Dur.	θ	z	Inst.	99% UL
000113	370	21	...	BATSE	5.5e-6
000131[1]	12	41	...	IPN	6.5e-7
000205	23	25	...	BSAX	6.9e-7
000206	10	39	...	BSAX	9.3e-7
000212	8	2.2	...	BATSE	1.1e-6
000220	2.4	49	...	BATSE	1.1e-5
000226	10	32	...	BATSE	3.4e-6
000226b[1]	94.5	32	...	IPN	7.8e-7
000301C	14	38	2.03	BATSE	...
000302	120	32	...	BATSE	6.8e-6
000314	12.8	45	...	BSAX	3.6e-5
000317	550	6.4	...	BATSE	7.9e-6
000330	0.2[*]	30	...	BATSE	1.0e-6
000331	55	38	...	BATSE	1.2e-5
000402	120	48	...	BSAX	4.5e-5
000408	2.5	31	...	BATSE	1.0e-6
000424	5	36	...	BATSE	7.6e-7
000508	30	34	...	BATSE	3.7e-6
000607[1]	0.12	42	...	IPN	4.6e-7
000615	10	39	...	BSAX	1.6e-6
000630	20	32	...	IPN	2.2e-6
000707[2]	18	43	...	IPN	1.9e-6
000707[2]	18	41	...	IPN	1.0e-6
000727	10	41	...	IPN	2.6e-6
000730	7	19	...	IPN	4.2e-7
000821[1]	8	27	...	IPN	6.9e-7
000830[1]	8	35	...	IPN	9.1e-7
000926	25	16	2.04	IPN	...
001017	10	42	...	IPN	2.2e-6
001018	31	32	...	IPN	2.1e-6
001019	10	20	...	IPN	1.1e-6
001105	30	8.5	...	IPN	1.4e-6
001204	0.44	48	...	BSAX	1.2e-5
010104	2	20	...	IPN	4.0e-7
010220	150	27	...	BSAX	2.1e-6
010613	152	25	...	IPN	2.9e-6
010706	48	37	...	IPN	2.6e-6
010903	41	49	...	IPN	2.9e-5
010921	24.6	10	0.45	HETE	**2.9e-5**[#]
011130	83.2	34	...	HETE	3.4e-6
011212	84.4	33	...	HETE	6.7e-6
020311	11.5	27	...	IPN	1.7e-7
020429[2]	16	39	...	IPN	4.6e-7
020429[2]	16	30	...	IPN	3.0e-7
020625b	125	38	...	HETE	5.7e-6
020702	26	34	...	IPN	1.4e-6
020908[1]	17	19	...	IPN	7.3e-7
020914	9	5.7	...	IPN	4.2e-7
021104	19.7	13	...	HETE	7.5e-7
021112	7.1	34	...	HETE	9.4e-7
021113	20	18	...	HETE	6.4e-7
021211	6	35	1.01	HETE	...
030413	15	27	...	IPN	1.0e-6
030823	56	33	...	HETE	2.8e-6
031026	0.24	45	...	IPN	1.1e-6
031220	23.7	43	...	HETE	4.0e-6
040506	175	49	...	IPN	6.0e-6
040924	0.6	43	0.859	HETE	**1.4e-3**[#]
041211	30.2	43	...	HETE	4.8e-6
041219a	520	27	...	INTGR.	5.8e-6
050124	4	23	...	Swift	3.0e-7
050213	17	23	...	IPN	1.3e-6
050319	15	45	3.24	Swift	...
050402	8	40	...	Swift	2.1e-6
050412	26	37	...	Swift	1.7e-6
050502	20	43	3.793	INTGR.	...
050504	80	28	...	INTGR.	1.3e-6
050505	60	29	4.3	Swift	...
050509b	0.128	10	0.226?	Swift	**1.1e-6**[#]
050522	15	23	...	INTGR.	5.1e-7
050607	26.5	29	...	Swift	8.9e-7
050703	26	26	...	IPN	1.2e-6
050712	35	39	...	Swift	2.5e-6
050713b	30	44	...	Swift	4.0e-6
050715	52	37	...	Swift	1.7e-6
050716	69	30	...	Swift	1.6e-6
050820	20	22	2.612	Swift	...
051103	0.17	50	0.001?	IPN	**4.2e-6**[#]
051109	36	9.7	2.346	Swift	...
051111	20	44	1.55	Swift	...
051211b	80	33	...	INTGR.	2.6e-6
051221	1.4	42	0.55	Swift	**9.8e-4**[#]
051221b	61	26	...	Swift	1.8e-6
060102	20	40	...	Swift	2.0e-6
060109	10	22	...	Swift	4.1e-7
060110	15	43	...	Swift	3.0e-6
060111b	59	37	...	Swift	2.3e-6
060114	100	41	...	INTGR.	5.1e-6
060204b	134	31	...	Swift	2.7e-6
060210	5	43	3.91	Swift	...
060218	10	44.6	0.03	Swift	**3.8e-5**[#]
060306	30	46	...	Swift	7.2e-6
060312	30	44	...	Swift	3.3e-6
060313	0.7	47	...	Swift	2.7e-6
060403	25	28	...	Swift	1.0e-6
060427b	0.22	16	...	IPN	2.1e-7
060428b	58	27	...	Swift	1.1e-6
060507	185	47	...	Swift	1.8e-5
060510b	330	43	4.9	Swift	...
060515	52	42	...	Swift	9.6e-6
060712	26	35	...	Swift	3.8e-6
060814	146	23	...	Swift	2.5e-6
060904A	80	14	...	Swift	2.4e-6
060906	43.6	29	3.685	Swift	...
061002	20	45	...	Swift	4.0e-6
061126	191	28	...	Swift	4.3e-6
061210	0.8	23	0.41?	Swift	**6.1e-6**[#]
061222a	115	30	...	Swift	5.6e-6